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Biomass energy potential and future prospect in Sudan

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Abstract

Sudan is an agricultural country with fertile land, plenty of water resources, livestock, forestry resources, and agricultural residues. Sudan is an energy importing country and the energy requirements have been supplied through imports that have caused financial problems. Because of the economical problems in Sudan today, the Sudanese energy policy should be concentrated on assurance of energy supply, reliability, domestic sufficiency, and in time, on economic terms, and renewability. Energy sources are divided into two main types; conventional energy (biomass, petroleum products, and electricity); and non-conventional energy (solar, wind, hydro, etc.). Sudan possesses a relatively high abundance of solar radiation, and moderate wind speeds, hydro, and biomass energy resources. Therefore as a renewable energy source, biomass (especially fuelwood) seems interesting because its share of the total energy production at 87% is high and the techniques for converting it to useful energy is easy. On the other hand, biomass may, however, see greatly expanded use in response to the environmental problems caused by fossil fuel use in the country. Like many tropical countries, Sudan has ample biomass resources that can be efficiently exploited in a manner that is both profitable and sustainable. Fuel-wood farming offers cost-effective and environmentally friendly energy solutions for Sudan, with the added benefit of providing sustainable livelihoods in rural areas. This article provides an overview of biomass energy activities and highlights future plans concerning optimum technical and economical utilization of biomass energy available in Sudan. Biomass has been proposed to have a central role to play in future, more sustainable energy scenarios. For this to become a reality, several real problems need to be overcome. In Sudan, as in other developing countries, modernization of biomass energy provision is an urgent necessity for the sake of human health, protection of the environment, and climate change abatement. Given sufficient recognition, resources and research biomass could become the environmentally friendly fuel of the future. Results suggest that biomass energy technologies must be

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encouraged, promoted, implemented, and fully demonstrated in Sudan.

Contents

1. Introduction

Available biomass energy resources in Sudan are now a major issue for the future strategic energy planning for the alternative to the fossil conventional energy to provide part of the local energy demand. Most of the political issues and resources are directed to established sources of energy, many of which now face serious environmental and other constraints, rather than biomass sources which government is increasingly regarding as a central part of long-term solutions to the energy environment dilemma. However, increasing energy service levels with the same environmental goals would imply greater exploitation of biomass energy sources and stronger measures for exploiting the potential of energy conservation [4].

The economic development of a country is dependent upon sustainable use of natural resources. Sudan's rapid population growth and its increasing pressure on these resources are posing a considerable challenge. Sudan recognizes the need to pursue the development of policies and strategies that are friendly to the environment in order to ensure sustainable growth, but more support (technical and financial) is needed to overcome the major obstacles by central government.

Poverty and the accompanying ignorance (lacking knowledge, generally not having many options other than exploiting their local environment) of natural resource degradation present major obstacles to sustainable development. In Sudan, about 75% of the population live in poor conditions (scarcity of food, water, clothes, education etc.), while 20% live in abject poverty. Small holders and pastoral groups have intensified exploitation of the land, contributing to widespread soil erosion [1]. Firewood and charcoal remain the dominant energy sources. These factors contribute to deforestation and desertification. Due to the very high consumption of firewood (45%), and charcoal (30%) for cooking in Sudan, providing 75% of the total energy consumption per annum, representing roughly 2×10^6 tonnes of wood harnessed from forest reserves, large-scale deforestation takes place [2].

Despite the many high levels of solar radiation, its use for energy supply is minimal. The number of cattle in Sudan is equal to the population (i.e. 35 million) but significant use of biogas has not yet occurred. Increased utilization of renewable energy technologies in Sudan remains constrained by poverty, underdevelopment and ignorance. Local Agenda 21, as well as such as local, regional and international conventions, call for practical action. Among the policies pursued in Sudan is a national program of tree-planting with the goal of planting three trees for each one cut. This program, if implemented, offers some hope for the rejuvenation of Sudan's forest resources [4].

One should not marginalize the international efforts to safeguard biological diversity and natural resources. But one must ask whether current rates of exploitation, consumption, and development have any relation to the sustainability vision? The current trend is for consumption patterns that require far more resources than the sustainable development we envision. Until we utilize resources at the optimum point in the present, consideration for future sustainability is simply a paradox or riddle!

2. Energy in rural Sudan

Sudan is the largest country of the African continent, with an area of approximately one million square miles (2.5×10^6 km^2). It extends between latitudes 3° N and 23° N, and longitudes 21° $45'$ E and 39° E. Sudan is a relatively sparsely populated country. The total population according to the 1999 census was 35×10^6 inhabitants. The growth rate is 2.8%/y, and population density is 14 persons per square kilometres. Sudan is rich in land and water resources [7].

Sudan is considered one of the least developed countries, with a per capita income of less than US$ 400, and a real growth rate of 0.2% of real gross domestic product (GDP) during the last ten years. However, during the 1980s, the real

growth rate of GDP was negative mainly due to drought and desertification. The backbone of Sudan's economy is its agricultural sector. To a great extent, the agricultural sector determines the economic performance of the Sudanese economy. In fact, the country could be rescued by proper organisation and utilisation of its agricultural potential. Recent development due to rehabilitation and improvement in the agricultural sector has raised the share to 41% as shown in Table 1.

Agriculture continues to play a pivotal role in economy. It directly influences the level of activities of all other sectors. It provides 90% of the raw materials for local industries, accounts for 80% of export earning, and provides income and employment for more than 80% of the population. The agricultural sector is composed of three distinct modes: irrigated agriculture, mechanised rain-fed agriculture, and traditional rain-fed agriculture and livestock raising.

The economy suffered from major structure imbalances between production and consumption, saving and exports. The poor performance of the economy is reflected in chronic budget deficits, mounting external debts, declining production, productivity, balance of payment position, and intense inflationary pressures. The gap between real and nominal GDP is depicted in Fig. 1, it reflects that the gap has kept growing at an increasing rate over the last years. This, however, can be explained by sharp increases in the consumer index. Current efforts to remedy the disastrous economic conditions include measures designed to eliminate government budget deficits, restriction of imports, promotion of exports, encouragement of private domestic and foreign investment, and most important, the tough measures taken by the existing government that put an end to dealing in foreign exchange [18].

The economic performance of some key sectors in the Sudanese economy virtually depends on the availability and regular supply of energy. The poor performance of the Sudanese economy can be partially explained by the continuous shortage in energy supply and its impact on productivity, capacity utilisation and growth in different sectors of the economy. Inadequate energy supplies have greatly affected the production and distribution of crops in the agricultural sector. Output losses due to the fuel shortages were higher in those which were mechanised rain-fed and pump-irrigated. In the industrial sector, shortage of power is considered by

Table 1
Estimate of gross domestic product by economic activity ($\times 10^6$ Sudanese Dinar) [18]

Sectors	79–84	85–95	96–2000
Agriculture	18661 (43%)	77342 (40%)	230923 (41%)
Commercial	5888 (14%)	26522 (14%)	83472 (15%)
Manufacturing and mining	2652 (6%)	13514 (7%)	43069 (8%)
Transport and communication	4323 (10%)	19391 (10%)	57984 (10%)
Construction and Public works	1917 (4%)	9879 (5%)	11200 (2%)
Electricity and water	664 (2%)	3916 (2%)	12340 (2%)
Government services	3322 (8%)	16853 (9%)	42095 (8%)
Personal services	1152 (3%)	5386 (3%)	17158 (3%)
Finance & real estate	4324 (10%)	20120 (10%)	60448 (11%)
Total	42903 (100%)	192923 (100%)	558688 (100%)

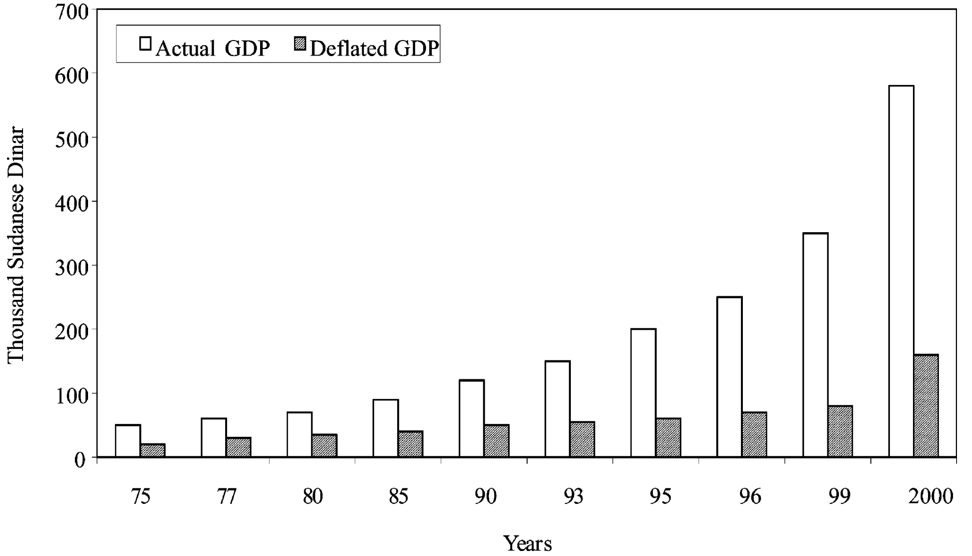

Fig. 1. Gross domestic product (actual and deflated).

many factors; higher production costs, lower capacity utilisation and poor economical performance [4].

The transport sector is totally dependent on oil and its products. It consumed 10% of the total energy consumption and utilised 60% of the total petroleum products supplied. Inadequate fuel supplies have created transportation bottlenecks which in turn have constrained production and distribution in most sectors of the economy.

Sudan, like most of the oil importing countries, suffered a lot from sharp increases in oil prices in the last decades, spending most of its hard currency earnings on importing oil, whilst failing to meet the increasing demand. The oil bill consumes more than 50% of the income earnings. The oil share is only 12% of the total energy consumption. Biomass (wood-fuel, agricultural residues and animal waste) utilised as fuel source is dominating Sudan's energy picture, accounting for about 87% of the country total energy consumption [3]. The electricity sector represented, at most, 1% of the total energy supplies (55% from hydropower and 45% from thermal generation) [5]. The household sector consumed 60% of the total electricity supplies.

The National Electricity Corporation (NEC) had the goal of improving the electricity system planning methodologically with regard to sustainability. Within this broad aim, the search has specific goals, including:

- To involve a wide-range of electricity sector participants, including utilities, regulators, environmentalists, and customers.
- To identify and implement a wider range of measures that will be more direct indicators of sustainability than the current response impacts and pollutant outputs.

- To create improved electricity sector modelling tools that simulate the electricity system operation under competition, and include transmission and distribution effects more directly into strategic planning.
- To consider technology options beyond the current next generation.
- To increase the comprehensiveness of current life-cycle assessment, by including a broader range of technologies, inputs and outputs are sensitive to technology choice versus the state of underlying production and transport infrastructures.
- To improve decision analysis tools to assist stakeholders in reaching a consensus on complex alternatives, option portfolios, and flexible contingencies.
- To make the data and models developed for understanding the relationship between power systems and sustainability, available and usable through Internet access.

The NEC handled a wide variety of electricity generation technologies (Table 2), including:

- Thermal (fossil, combined cycle, combustion turbines).
- Storage (pumped hydro, batteries, compressed air).
- Non-dispatchable technologies (solar, wind, cogeneration, load management).

The data required to perform the trade-off analysis simulation can be classified according to the divisions given in Table 3: the overall system or individual plants, and the existing situation or future development.

Sudanese rural households without access to electricity rely on five types of energy carriers: fuel-wood, kerosene, dry cell batteries, animal power and human power, as shown in Table 4. Fuel-wood is used for cooking, water heating, building materials, and animal fodder preparation. Kerosene is used for lighting and igniting fires. Dry cell batteries are used for portable light in torches and for powering radios, and tape recorders. Animal power (and sometimes human power) is used for transport services and farming activities such as ploughing and threshing. The substitution of electricity for these energy carriers offers versatility in end-uses as well as positive socio-economic and environmental impacts [4].

Fuel-wood is the most common energy carrier and requires significant man-power to acquire. A rural household in Sudan typically spends the equivalent of 30

Table 2
Comparison between different energy consumed in Sudan (GWh)

Year	Electricity	Petroleum	Biomass	Renewable technologies
1975	800	550	3000	50
1980	900	600	3500	60
1985	1200	650	4000	100
1990	1300	700	6000	120
1995	1400	800	7000	150
2000	1500	900	8000	200

Table 3
Classifications of data requirements

	Plant data	System data
Existing data	Size	Peak load
	Life	Load shape
	Cost (fixed and var. O&M)	Capital costs
	Forced outage	Fuel costs
	Maintenance	Depreciation
	Efficiency	Rate of return
	Fuel	Taxes
	Emissions	
Future data	All of above, plus	System lead growth
	Capital costs	Fuel price growth
	Construction trajectory	Fuel import limits
	Date in service	Inflation

person-days per year, cutting, splitting, drying and transporting fuel-wood. This human power requirement competes with the need for human labour in agricultural or other types of production, thus leading to a constraint to development in rural Sudan. All fuel-wood that can be substituted is therefore likely to lead to improved livelihoods in Sudan by freeing labour for more productive activities. Sudan has one of the highest levels of fuel-wood consumption per capita in the world, estimated at over 2 tonnes/capita/year [6]. Kerosene provides a better lighting service than fuel-wood, but is costlier and generally more difficult to obtain. Kerosene has negative impacts on indoor air quality and human health, due to high emissions of smoke and particles [5].

Dry cell batteries are a practical but expensive form of mobile fuel that is used by the rural Sudanese when moving around at night and for powering radios and

Table 4
Energy carrier and energy services in rural Sudan

Energy carrier	Energy end-use	Typical annual household consumption
Fuel-wood	Cooking	10 tonnes [28]
	Water heating	
	Building materials	
	Animal fodder preparation	
Kerosene	Lighting	100 litres [26]
	Ignition fires	
Dry cell batteries	Lighting	50 pairs [21]
	Small appliances	
Animal power	Transport	
	Land preparation for farming	
	Food preparation (threshing)	
Human power	Transport	
	Land preparation for farming	
	Food preparation (threshing)	

other small appliances. The high cost of dry cell batteries is financially constraining for rural Sudanese households, but their popularity gives a good indication of how valuable a versatile fuel like electricity is in rural Sudan. Dry cell batteries can constitute an environmental hazard unless they are recycled in a proper fashion [8].

Sudan possesses a relatively high abundance of solar radiation (20–24 MJm^{-2} day^{-1}), and moderate wind speeds (3–5 ms^{-1}). Also, it has good resources especially in water, land agriculture and livestock. These dimensions show the potential of biomass energy resources in Sudan. Various attempts have been made to quantitatively assess the biomass resources. However, apart from studies in 1983 initiated by the National Energy Administration (NEA) during its national energy assessment study, most of the previous attempts were either improperly documented, or have methodological constraints and become out of date. This is primarily a result of the dynamics of biomass resource evolution in response to over-cutting, drought, agricultural expansion and low investment [7].

3. Available land for biomass utilization

The total area of the land of Sudan is 250×10^6 hectares. The land use in the country is classified as shown in Table 5. There are arable land (8×10^6 hectares), pasture (30×10^6 hectares), forest (108×10^6 hectares), savannah grassland (21×10^6 hectares), and 38×10^6 hectares used for other purposes.

Estimation of the total growing stock of not only woodlands and forests, but also the woody biomass in semi-desert, bush-lands and trees on private farms, mechanized agricultural schemes and shelterbelts within irrigated schemes. The growing stock estimates are of the order of 22.2 m^3 to 28.6 m^3 per hectare of productive forests with their actual value ranging from 150 m^3 per hectare for mountain forests of the southern states to less than one cubic meter per hectare in the desert areas. The area of gazetted forest estate (forest reserves) is estimated to be

Table 5
Land use distribution in Sudan

Land use	10^6 Hectares	Share of total	Comments
Natural forest	94	37.6%	Protected areas
Forest plantations	14	5.6%	Commercial or civil
Savannah grasslands	21	8.4%	Gum, tobacco, groundnut
Trees in swamps	1	0.4%	Water hyacinth, papyrus
Arable land	8	3.2%	Sugar canes, cotton, gum
Pasture	30	12.0%	Grass, bushes
Other land uses	38	15.2%	Urban, housing, roads, shores, rivers, mountains
No use	44	17.6%	Unclassified or protected
Total land area	250	100.0%	

1.05×10^6 hectares representing only 1% of the total area of forests and woodlands [8,9].

Sudan meets approximately 87% of its energy needs with biomass. Table 6 shows the energy consumption in Sudan. Biomass is the most consumed type of energy. Biomass, i.e. wood fuel, animal waste, and agricultural residues utilised as fuel sources clearly dominating Sudan's energy picture. During the last two decades, there was a problem of drought and desertification, which was the result of the removal and cutting of the vegetation for the purpose of mechanised agriculture and fuel-wood production. The total area and volume of Sudan's forestry resource are 108×10^6 hectares and 1.966×10^6 cubic meter (m^3), respectively. About 70% of this was located in the southern region, and the forestry area decreased towards the north of Sudan (Table 7).

Sudan has a significant crop residue base. The main crop residues suitable for energy use are cotton stalks, groundnut shells, sugar, wheat, sorghum, millet, sesame tobacco, and many other different crops. The available biomass resources including agricultural, aquatic weeds and various animal wastes are shown in Table 8. Depending on the Eastern region survey conducted by National Energy administration [21], it was estimated that, only 11% of agriculture residues resources and 8% of animal waste are being utilised for energy. The supply of agriculture residues is 44.5×10^6 kg, of animal 900×10^6 kg, and of bagasse is 840×10^6 kg. Table 9 shows the recorded figures from the National Forestry Corporation (NFC). The production of reserved forests must not exceed the allowable cut planned by NFC, which is decreasing by 2.2% annually. This decrement is due to the depletion of the growing stock [22].

Due to the lack of the actual consumption data, three estimates have been carried out for biomass consumption. The first estimate depends on the per capita consumption estimated by the United Nations Development Programme [23] in the household sector for urban and rural population. The second estimate is based upon per capita consumption for rural and urban population from surveys in household sector conducted by [24] for the Northern, Khartoum, and Southern regions, [9] for the Central region, [25] for Kordofan, and [26] for the Eastern region. The third estimate depends on the per capita consumption estimates (Table 10). It was found that the third estimates are the most reliable. It should be

Table 6
Total energy consumption ($\times 10^3$ TOE) [19]

Fuels	80–85	86–96	97–2000
Petroleum	1040984	1203552	1219118
Electricity	54236	104659	102400
Firewood	1996804	2346961	2727437
Charcoal	1290555	1516865	1762771
Other biomass	381795	448746	521495
Total biomass	3669154	4312572	5011703
Total	4764374	5620783	6333221

Table 7
Forestry resources in Sudan [20]

Regions	Total area ($\times 10^3$ Hectares)	Average volume (m^3)	Total volume (m^3)
Northern	0	0	0
Eastern	2748	3	7008
Central	5124	5	25532
Khartoum	5	60	300
Kordofan	11628	11	122828
Darfur	17693	27	477200
Southern	71096	19	1332953
Total	108294	125	1965821

recognised that this situation is unlikely to change for the next one or two decades. However, there is a need to increase energy availability and also to find alternatives to the rapidly decreasing wood supplies in many rural areas.

Table 11 represents the total biomass consumption in Sudan. The industrial and service sectors consume 3 and 4% of the total biomass energy, respectively. Biomass consumption is increasing annually due to the high demand of fuel-wood.

Table 8
Annual total different biomass supply in regions of Sudan ($\times 10^3$ kg)

Regions	Agricultural residues	Animal waste	Bagasse
Northern	288	8548	8644
Eastern	11530	84316	84414
Central	21550	107342	131744
Khartoum	0	5766	5170
Kordofan	2733	234086	236819
Darfur	6901	173376	174067
Southern	1464	290599	197875
Total	44466	904033	838733

Table 9
Annual wood allowable for cut (m^3)

Regions	Plantation	Natural	Total
Northern	6846	0	6846
Eastern	19240	200772	220012
Central	86378	758457	844835
Kordofan	5697	2555412	2561109
Darfur	10264	8204620	8214884
Khartoum	6002	25674	31676
Equatorial	29492	9654676	9684168
Bahar El Gazal	8436	7134419	7142854
Upper Nile	169	3999174	3999342
Total	165677	32533204	32698881

Table 10
Per capita consumption for household (10^3 kg)

Fuel	Wood		Charcoal	
Region	Urban	Rural	Urban	Rural
Northern	0.28	0.38	0.83	1.08
Eastern	0.35	0.40	2.21	2.04
Central	0.30	0.58	2.25	2.05
Kordofan	0.41	1.23	5.29	2.30
Darfur	0.41	1.23	5.29	2.30
Khartoum	0.48	0.26	0.93	0.94
Equatorial	0.48	1.40	0.88	0.27
Bahar El Gazal	0.88	1.36	1.00	0.27
Upper Nile	0.58	0.66	0.76	0.18

The increase in demand for fuel-wood lead to the depletion of the forests area, which was estimated at 4% depletion annually (Table 12). Comparing the allowable cut with wood-fuel consumption, it was found that while in the 1980s the allowable cut covered 70% of the fuel-wood demand, it covered 51% in the 1990s (Fig. 2). This means that illegal cutting had been occurred to meet the increase in the fuel-wood demand, and it is increasing annually.

The available growing stock resource is unevenly distributed between northern and southern states, and between provinces within estates (33% of the total growing stock in the northern states, and 67% in the southern states). Furthermore, within the northern states provinces, 93% of the available growing stock occurs in the provinces of southern Darfur and southern Kordofan combined. By contrast, the northern provinces probably has less than 3% of the growing stock of the state.

The population distribution, on the other hand, shows the reverse. In 1999, 78% of the total population was concentrated in the northern states whereas the southern states had only 22% of the total population, thus leading to a considerable

Table 11
National biomass consumption ($\times 10^3$ kg)

Years	Wood	Charcoal	Other biomass	Total
1980	1969514	1272917	376577	3619008
1983	2024094	1308193	387013	3719300
1985	2080187	1344447	397738	3822372
1987	2137835	1381705	408761	3928301
1990	2197001	1419944	420074	4037019
1993	2255621	1457831	431282	4144734
1995	2315933	1496812	442814	4255559
1997	2377989	1536919	454679	4369587
1998	2623925	1695870	501703	4821498
1999	2689635	1738339	514267	4942241
2000	2765240	1787203	528723	5081166

Table 12
Area of forests [27]

Regions	Number of forest	Area under reserved
Northern	67	95880
Eastern	157	1278580
Central	334	1745919
Khartoum	22	52558
Kordofan	93	1003158
Darfur	72	1066067
Southern	N.A	N.A
Total	745	5242162

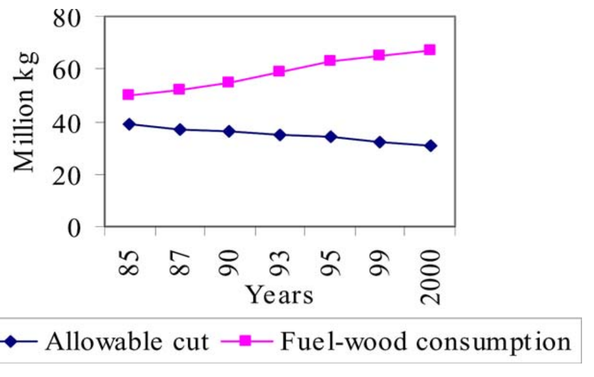

Fig. 2. Forest allowable cut versus fuel-wood consumption.

imbalance between fuel-wood biomass resources on the one hand and the consumption pattern (determined by the distribution of population). On the other is a major contributor to the rapid depletion of the forestry resources in the north.

4. Biomass utilization

Table 13 shows biomass energy consumption and distribution among different sectors in Sudan. Sudan, like most oil importing countries, suffered from the sharp fluctuations in oil prices over the last decades. Biomass energy supply continued to be the dominant energy supply, providing 87% of total energy consumption since the 1970's. Out of total fuel-wood and charcoal supplies, 92% was consumed in household sector with most of the firewood consumption in rural areas (5–10 kg per day) [10].

The data available are the approximate quantities calculated according to an average estimated yield factor per unit (kg). Often, the annual availability of fuel-wood varies considerably due to many factors related to the prevailing conditions

Table 13
Biomass energy consumption pattern in Sudan (10^3 m^3) [22]

Sector	Firewood	Charcoal	Total	Percent
Residential	6148	6071	12219	89
Industries	1050	12	1062	8
Commercial	32	284	316	2
Quranic Schools	209	0	209	2
Total	7439	6367	13806	100
Percent	54%	46%	100	

of country such as policies, strategies, meteorological conditions primarily, methods and techniques adopted for production, and hazards. There are alternative competitive uses as shown in Table 14, mainly for building materials (roofs or plastering), brick making, animal fodder, papers, cardboard, and fertilizer. The most promising agricultural residues, which have high availability factors and high potential for energy production, are cotton stalks and groundnut shells. The effective economic utilization of these resources are shown in Table 15, but their use is hindered by many problems such as those related to harvesting, collection, and transportation, besides the photo-sanitary control regulations. Biomass energy is experiencing a surge in interest stemming from a combination of factors, e.g. greater recognition of its current role and future potential contribution as a modern fuel, global environmental benefits, its development and entrepreneurial opportunities, etc. Possible routes of biomass energy development are shown in Table 16.

(a) Biomass energy for domestic needs:

1. Population increase
2. Urbanization
3. Agricultural expansion
4. Fuel-wood crisis
5. Ecological crisis
6. Fuel-wood plantations

Table 14
Biomass residues, current use and general availability

Type of residue	Current use/availability
Wood industry waste	No residues available
Vegetable crop residues	Animal feed
Food processing residue	Energy needs
Sorghum, millet, wheat residues	Fodder, and building materials
Groundnut shells	Fodder, brick making, direct fining oil mills
Cotton stalks	Domestic fuel considerable amounts available for short period
Sugar, bagasse, molasses	Fodder, energy need, ethanol production (surplus available)
Manure	Fertilizer, brick making, plastering (*Zibala*)

Table 15
Effective biomass resource utilization

Subject	Tools	Constraints
Utilization and land clearance for agriculture expansion	• Stumpage fees • Control • Extension • Conversion • Technology	• Policy • Fuel-wood planning • Lack of extension • Institutional
Utilization of agricultural residues	• Briquetting • Carbonisation • Carbonisation and briquetting • Fermentation • Gasification	• Capital • Pricing • Policy and legislation • Social acceptability

Table 16
Agricultural residues routes for development

Source	Process	Product	End use
Agricultural residues	Direct	Combustion	Rural poor Urban household Industrial use
	Processing	Briquettes	Industrial use Limited household use
	Processing	Carbonisation (small scale)	Rural household (self sufficiency)
	Carbonisation	Briquettes	Urban fuel
	Fermentation	Carbonised	
		Biogas	Energy services HouseholdIndustry
Agricultural, and animal residues	Direct	Combustion	(save or less efficiency as wood)
	Briquettes	Direct combustion	(similar end use devices or improved)
	Carbonisation	Carbonised	Use
	Carbonisation	Briquettes	Briquettes use
	Fermentation	Biogas	Use

7. Community forestry
8. Improved stoves
9. Agro-forestry
10. Improved charcoal production
11. Residue utilization

(b) Biomass energy for petroleum substitution:

1. Oil price increase
2. Balance of payment problems
3. Economic crisis
4. Fuel-wood plantations
5. Residue utilization
6. Wood based heat and electricity
7. Liquid fuels from biomass
8. Producer gas technology

(c) Biomass energy for development:

1. Electrification
2. Irrigation and water supply
3. Economic and social development
4. Fuel-wood plantations
5. Community forestry
6. Agro-forestry
7. Briquettes
8. Producer gas technology

5. Sudan's experience in biomass energy technologies

In Sudan, great attention is given to the utilisation of the biomass, and the overall biomass energy potential of the country. Three distinct groups contribute to research, development and utilisation of the resources. These are:

1. Research institutes
2. Universities, and
3. Private sector

Participation and roles in technology diffuse:

1. Government:
   - Improved economic competitiveness of technology
   - Support information flow technical financial viability, and resource assessment
   - Support training
   - Undertake R&D
2. NGOs:
   - Training
   - Extension

- Assessment of local needs
- Demonstration
- Promotion of small-scale production

3. Private Sector:

- Production
- Assembly, maintenance and spare-parts supply
- Marketing

Two major studies [11,12] for the utilisation of biomass residues for energy in Sudan have been conducted through joint foreign projects such as:

1. Groundnut shells briquetting (UNDP/UNSO/NEA)
2. Biogas and briquettes from water hyacinth (GTZ/PPD/German)
3. Cotton stalks gasification (UNDP/ERI/NEA/France)
4. Direct combustion (SIDA)
5. Carbonisation (GTZ/ERI)
6. Carbonisation and briquetting (DIGS/UNIDO/USAID/BTG/ERI)

6. Biomass technologies

Agriculture is the source of a considerable sum of hard currency and 33% of the Gross National Product (GDP) that is needed for the control of balance of payment in the country's budget, as well as being the major source of raw materials for local industry. Biomass resources play a significant role in energy supply in Sudan as in all other developing countries. Biomass resources should be divided into residues or dedicated resources, the latter including firewood and charcoal can also be produced from forest residues.

Approximately 13×10^6 m^3 of biomass are consumed per year as shown in Table 13. To avoid resource depletion, Sudan is currently undergoing a reforestation programme on 1.05×10^6 hectares. Experiencing biomass residues is more economically exploitable and more environmentally benign than dedicated biomass resources. There exists a variety of readily available sources in Sudan, including agricultural residues such as sugar cane bagasse, molasses, cotton stalks, groundnut shells, tree/forest residues, aquatic weeds, and various animal wastes (Table 17).

The most promising agricultural residues which have high availability factor and high potential for energy production, are cotton stalks and groundnut shells [12].

The use of biomass through direct combustion has long been, and still is, the most common mode of biomass utilisation as shown in Tables 14–16. Examples for dry (thermo-chemical) conversion processes are charcoal making from wood (slow pyrolysis), gasification of forest and agricultural residues (fast pyrolysis—this is

Table 17
Annual biomass volume sources available in Sudan (10^6 m^3)

Source	Volume (10^6 m^3)
Natural and cultivated forestry	2.9
Agricultural residues	5.2
Animal wastes	1.1
Water hyacinth and aquatic weeds	3.2
Total	13.4

still in the demonstration phase), and of course, direct combustion in stoves, furnaces, etc. Wet processes require a substantial amount of water to be mixed with the biomass.

Biomass technologies include: biogas, briquetting, gasification, improved charcoal, carbonisation, and improved stoves

Direct burning of fuel-wood and crop residues constitute the main usage of Sudan biomass, as is the case with many developing countries. However, the direct burning of biomass in an inefficient manner causes economic loss and adversely affects human health. In order to address the problem of inefficiency, research centres around the country have investigated the viability of converting the resource to a more useful form, namely solid briquettes and fuel gas.

6.1. Briquetting

Briquetting is the formation of a char (an energy-dense solid fuel source) from otherwise wasted agricultural and forestry residues. One of the disadvantages of wood fuel is that it is bulky with a low energy density and is therefore expensive to transport. Briquette formation allows for a more energy-dense fuel to be delivered, thus reducing the transportation cost and making the resource more competitive. It also adds some uniformity, which makes the fuel more compatible with systems that are sensitive to the specific fuel input [13].

Briquetting of agricultural residues in Sudan started in 1980, where a small entrepreneur constructed a briquetting plant using groundnut shells in Khartoum. The second plant was introduced in Kordofan (western Sudan), and the plant had a capacity of 2 tonnes per hour with a maximum 2000 tonnes per season. Another prototype unit was worked in Nyala with a capacity of 0.5 tonnes per hour (i.e. 600 tonnes per season). In central Sudan, a briquetting plant of cotton stalks was installed at Wad El Shafie with a capacity of 2 tonnes per hour (i.e. 2000 tonnes per season). The ongoing project in New Halfa is being constructed to produce 1200 tonnes per season of bagasse briquettes. A number of factories have been built for the carbonisation of agricultural residues, namely cotton stalks. The products are now commercialised. More than 2000 families have been trained to produce their cooking charcoal from the cotton stalks.

Table 18
Charcoal cost in Khartoum (Sudanese Dinar/sack)

Cost component	Cost (Sudanese Dinar/sack)	Percent of total cost
Labour	20	20
Water	7	7
Sack	4	4
Loading and unloading	4	4
Government royalties	5	5
Transport to Khartoum	15	15
Middlemen	5	5
Others	40	40
Total	100	100

Labour, transportation and sacking costs are the main factors affecting the price of charcoal (Table 18). The price of charcoal varies from one season to another, where it has the lowest price in the production season (March–June), and the highest price at other times (July–January). The price fluctuations are due to the lack of labour, the rapid increase in transportation costs, and disasters such as rain and flooding.

6.2. Improved stoves

In Sudan, most urban households burn charcoals on traditional square 'Canun' stove that have very low fuel-to-heat conversion efficiencies. The following prototypes were all tried and tested in Sudan [14]:

- The metal clad Kenyan Jiko
- The vermiculite lined traditional Kenyan Jiko
- The all-ceramic Jiko in square metal box
- The open draft Dugga stoves
- The controlled draft Dugga stoves
- The Umeme Jiko 'Canun Al Jadeed'

Local traditional stoves were tested, improved, and commercially used in Sudan [15]:

- Traditional muddy stoves
- Bucket stoves
- Tin stoves

Another area in which rural energy availability could be secured where woody fuels have become scarce, are the improvements of traditional cookers and ovens to raise the efficiency of fuel saving. Also, by planting fast growing trees to provide a constant fuel supply. The rural development is essential and economically important since it will eventually lead to better standards of living, people's settlement, and self sufficient in the following:

- Food and water supplies.
- Better services in education and health care.
- Good communication modes.

6.3. Gasification

Gasification is based on the formation of a fuel gas (mostly CO and H_2) by partially oxidising raw solid fuel at high temperatures in the presence of steam or air. The technology can use wood chips, groundnut shells, sugar cane bagasse, and other similar fuels to generate capacities from 3 kW to 100 kW. Three types of gasifier designs have been developed to make use of the diversity of fuel inputs and to meet the requirements of the product gas output (degree of cleanliness, composition, heating value, etc.).

6.4. Biogas

Presently, Sudan uses a significant amount of kerosene, diesel, firewood, and charcoal for cooking in many rural areas. Biogas technology was introduced to Sudan in the mid seventies when GTZ designed a unit as part of a project for water hyacinth control in central Sudan. Anaerobic digesters producing biogas (methane) offer a sustainable alternative fuel for cooking and lighting that is appropriate and economic in rural areas. In Sudan, there are currently over 200 installed biogas units, covering a wide range of scales appropriate to family, community, or industrial uses. The agricultural residues and animal wastes are the main sources of feedstock for larger scale biogas plants.

There are, in practice, two main types of biogas plant that have been developed in Sudan; the fixed dome digester, which is commonly called the Chinese digester (120 units each with volumes of 7–15 m^3). The floating gasholder known as the Indian digester (80 units each with volumes of 5–10 m^3). The solid waste from biogas plants adds economic value by providing valuable fertilizer [16].

Biogas technology can not only provide fuel, but is also important for the comprehensive utilization of biomass forestry, animal husbandry, fishery, agricultural economy, protecting the environment, realizing agricultural recycling, as well as improving sanitary conditions in rural areas. The introduction of biogas technology on a wide scale has implications for macro planning such as the allocation of government investment and effects on the balance of payments. Factors that determine the rate of acceptance of biogas plants, such as credit facilities and technical backup services, are likely to have to be planned as part of general macro-policy, as do the allocation of research and development funds [16].

6.5. Sugar cane biomass

Residuals from the sugar cane industry represent by far the most important source of current and potential biomass resources in Sudan. The sugar industry in Sudan goes back fifty years and Sudan has been one of the world's leading sugar

Table 19
Annual sugarcane bagasse available in Sudan (10^3 tonnes)

Factory	Design capacity	Yearly bagasse production 1995–2001
Kenana	300	266
El Genaid	60	53
New Halfa	75	65
Sennar	100	58
Asalaia	100	60
Total	635	502

producers. Sugar cane plantations cover one-fifth of the arable land in Sudan. In addition to raw sugar, Sudanese enterprises produce and utilize many valuable cane co-products for feed, food, energy and fibre. At present, there are 5 sugar factories as illustrated in Table 19.

Sugar cane bagasse and sugar cane trash already provide a significant amount of biomass for electricity production, but the potential is much higher with advanced cogeneration technologies. Most sugar factories in Sudan, as elsewhere in the developing world, can produce about 15–30 kWh per tonne of cane. If all factories were fitted with biomass gasifier-combined cycle systems, 400–800 kWh of electricity could be produced per tonne of cane, enough to satisfy all of Sudan's current electricity demand.

In Sudan there are no alcohol distilleries. The three factories were closed with Islamic Laws in 1983. The current circumstances suggest that Sudan should consider expanding production for use as transportation fuel, but this option has not yet been pursued. The alcohol was used for a variety of applications, mainly for medical purposes and rum production. Blending with gasoline would also have direct environmental advantages by substituting for lead as an octane enhancer.

7. Major research gaps

A major gap with biomass energy is that research has usually been aimed at obtaining supply and consumption data, with insufficient attention and resources being allocated to basic research, to production, harvesting and conservation process. Biomass has not been closely examined in terms of a substitute for fossil fuels compared to carbon sequestration and overall environmental benefits related to these different approaches. To achieve the full potential of biomass as a feedstock for energy, food, or any other uses, requires the application of considerable scientific and technological inputs [17]. The aim of any modern biomass energy systems must be:

1. To maximise yields with minimum inputs;
2. Utilisation and selection of adequate plant materials and processes;

3. Optimum use of land, water, fertilizer;
4. Create an adequate infrastructure and strong R&D base.

But social policy conditions are critical.

This is still very much lacking particularly under developing country conditions. Sub-Saharan countries i.e. Sudan, suffer particularly from poor technological, capital, financial, and skills resource base. During the 1970s and 1980s, different biomass energy technologies were perceived in sub-Saharan Africa as a panacea for solving acute problems. On account of these expectations, a wide range of activities and projects were initiated. However, despite considerable financial and human efforts, most of these initiatives have unfortunately been a failure.

Future research efforts should be concentrate on the following areas:

- Directed R&D in the most promising areas of biomass to increase energy supply and to improve the technological base.
- Formulate a policy framework to encourage entrepreneurial and integrated process.
- Pay more attention to sustainable production and use of biomass energy feedstocks, methodology of conservation and efficient energy flows.
- More research aimed at pollution abatement.
- Greater attention to interrelated socio-economic aspects.
- Support R&D on energy efficiency in production and use.
- Improve energy management skills and take maximum advantage of existing local knowledge.
- Closely examine past successes and failures so as to assist policy makers with well-informed recommendations.

8. Recent trends of research on biomass energy

There are many emerging biomass technologies with large and immediate potential applications e.g. biomass gasifier/gas turbine (BGST) systems for power generation with pilot plants, improved techniques for biomass harvesting, transportation and storage. Gasification of crop residues such as rice husks, groundnut shells etc. with plants already operating in China, India, and Thailand. Treatment of cellulosic materials by steam explosion which may be followed by biological or chemical hydrolysis to produce ethanol or other fuels, cogeneration technologies, hydrogen from biomass, striling energies capable of using biomass fuels efficiently etc. The main research in Sudan of recent years can thus be summarised as follows:

1. Direct combustion of biomass to produce heat, steam or electricity.
2. Production of liquid fuels such as ethanol and methanol, vegetable oils, and electricity cogeneration.
3. Production of charcoal and char.
4. Thermo-chemical conversion of biomass for generating heat and electricity.
5. Anaerobic digestion of biomass residues, wastes, and dung.

9. Barriers to implementation

The afforestation program appears an attractive option for the country to pursue in order to reduce the level of atmospheric carbon by enhancing carbon sequestration in the nation's forests, which would consequently mitigate climate change. However, it is acknowledged that certain barriers need to be overcome if the objectives were to be fully achieved. These include the following:

- Low level of public awareness of the economic/environmental benefits of forestry.
- The generally low levels of individual income.
- Pressures from population growth.
- The land tenural system, which makes it difficult (if not possible) for individuals to own or establish forest plantations.
- Poor pricing of forest products especially in the local market.
- Inadequate financial support on the part of governments.
- Weak institutional capabilities of the various Forestry Departments as regards technical manpower to effectively manage tree plantations.

10. Economic incentives to protect the environment

In some countries, a wide range of economic incentives and other measures are already helping to protect the environment. These include: (1) Taxes and user charges that reflect the costs of using the environment e.g. pollution taxes and waste disposal charges; (2) Subsidies, credits and grants that encourage environmental protection; (3) Deposit-refund systems that prevent pollution on resource misuse and promote product reuse or recycling; (4) Financial enforcement incentives, e.g. fines for non-compliance with environmental regulations; (5) Tradable permits for activities that harm the environment.

11. Mitigation measures

Potential mitigation measures to decrease greenhouse gas (GHG) emissions from the oil industry and decelerate the threat of global climate change may include the following:

- Controlling GHGs emissions by improving the efficiency of energy use, changing equipment and operating procedures.
- Controlling GHGs emission detection techniques in oil production, transportation and refining processes in Sudan.
- More efficient use of energy-intensive materials and changes in consumption patterns.
- A shift to low carbon fuels, especially in designing new refineries.
- The development of alternative energy sources (e.g. biomass, solar, wind, hydro-electrical and cogeneration).

- The development of effective environment standards, policies, laws and regulations particularly in the field of oil industry.
- Activating and supporting environmental and pollution control activities within the Ministry of Energy and Mining (MEM) to effectively cope with the evolving oil industry in Sudan.

12. Recommendations

1. More efficient use of energy-intensive materials and changes in consumption patterns.
2. The development of effective environment standards, policies, laws and regulations particularly in the field of oil industry.
3. The development of alternative energy sources (e.g. biomass, solar, wind, hydroelectric and cogeneration).
4. The non-technical issues, which have recently gained attention, include:
   - Environmental and ecological factors e.g. carbon sequestration, reforestation and revegetation.
   - Biomass as a CO_2 neutral replacement for fossil fuels.
   - Greater recognition of the importance of renewable energy, particularly modern biomass energy carriers, at the policy and planning levels.
   - Greater recognition of the difficulties of gathering good and reliable renewable energy data, and efforts to improve it.
   - Studies on the detrimental health efforts of biomass energy particularly from traditional energy users.
5. Local manufacture, whenever possible, is to be emphasised to avail biomass energy devices since limited funds are the main constraints in commercialisation and dissemination of the technology. Low cost devices as well as reliable devices have to be provided.
6. To encourage the private sectors to assemble, install, repair and manufacture biomass energy devices via investment encouragement, more flexible licensing procedures.
7. To encourage co-operation between nations, a fact which will be much easier in this era of information and the communications revolution.
8. To direct Sudan resources away from feeding wars and the arms industry towards real development, which will serve the noble ends of peace and progress.

13. Conclusions

Even with modest assumptions about the availability of land, a comprehensive fuel-wood farming programs for Sudan offers significant energy, economic and

environmental benefits. These benefits would be dispersed in rural areas where they are greatly needed and can serve as linkages for further rural economic development. The nation as a whole would benefit from savings in foreign exchange, improved energy security, and socio-economic improvements. With a nine-fold increase in forest–plantation cover, the nation's resource base would be greatly improved. The international community would benefit from pollution reduction, climate mitigation, and the increased trading opportunities that arise from new income sources. The aim of any modern biomass energy systems must be:

- To maximise yields with minimum inputs.
- Utilisation and selection of adequate plant materials and processes.
- Optimum use of land, water, and fertiliser.
- Create an adequate infrastructure and strong R&D base.

Furthermore, Sudan is investigating the potential of making use of more and more of its waste. Household waste, vegetable market waste, and waste from the cotton stalks, leather, and pulp; and paper industries can be used to produce useful energy either by direct incineration, gasification, digestion (biogas production), fermentation, or cogeneration.

Appendix A: Facts about Sudan

Full country name	Republic of the Sudan
Total area	One million square miles (2.5×10^6 square kilometres). Land 2.376×10^6 square kilometres.
Population	35×10^6 inhabitants (July 1999 est.)
Capital city	Khartoum (population 5 million)
Language	Arabic (official), English, Nubian, Ta Bedawie, diverse dialects of Nilotic, Nilo – Hamitic, Sudanic languages
Religions	Sunni Muslim 70% (in north), indigenous beliefs 25%, Christian 5% (mostly in south and Khartoum)
GDP per head	US$ 533
Annual growth	4% (1997 est.)
Inflation	23% (1998 est.)
Ethnic groups	Black 52%, Arab 39%, Beja 6%, Foreigners 2%, others 1%
Agriculture	Agriculture is the backbone of economic and social development. 62% of the population are employed in agriculture. Agriculture contributes 33% of the gross national products (GNP), and 95% of all earnings.

Animal wealthy	35×10^6 head of cattle. 35×10^6 head of sheep. 35×10^6 head of goats. 3×10^6 head of camels. 0.6×10^6 head of horses and donkeys. Fish wealth 0.2×10^6 tonnes of food annually. Wildlife, birds and reptiles.
Biomass energy available	2.9×10^6 tonnes from natural, and cultivated forests. 6.2×10^6 tonnes from agricultural residues. 1.1×10^6 tonnes from animal wastes. 3.2×10^6 tonnes from water hyacinth.
Biomass energy consumption	87% of the total energy supply. 92% consumed in household sector. 3.4% consumed by industrial sector. 4.6% consumed in commercial, constructions, and Quranic schools.
Environment	Inadequate supplies of potable water, wildlife populations threatened by excessive hunting, soil erosion, and desertification.
International agreements	Party to: Biodiversity CBD, climate change Kyoto, desertification, endangered species, law of the sea, nuclear test ban, ozone layer protection.

Appendix B: Typical solid waste components from Sudanese cities

Waste components	Percentage (%)
Vegetable, fruit, and animal matter	27.0
Dry grass and leaves	5.6
Paper and paper products	10.9
Plastic materials	5.4
Leather, foam and human hair	3.7
Cotton, jute and burlap	6.1
Rubber including cycle and auto tyres	2.9
Metals (tins, iron, and aluminium)	2.0
Concrete, pebbles, earth, sands and dust	25.0
Ash	9.0
Wood	0.4
Glass and ceramics	2.0
Total	100.0

Appendix C: Final energy projections including biomass (Mtoe) [28]

Region	1995			
	Biomass	Conventional	Total	Share of Energy Biomass (%)
Africa	205	136	341	60
China	206	649	855	24
East Asia	106	316	422	25
Latin America	73	342	416	18
South Asia	235	188	423	56
Total developing countries	825	1632	2456	34
Other non-OECD countries	24	1037	1061	1
Total non-OECD countries	849	2669	3518	24
OECD countries	81	3044	3125	3
World	930	5713	6643	14
Region	2020			
	Biomass	Conventional	Total	Share of Energy Biomass (%)
Africa	371	266	631	59
China	224	1524	1748	13
East Asia	118	813	931	13
Latin America	81	706	787	10
South Asia	276	523	799	35
Total developing countries	1071	3825	4896	22
Other non-OECD countries	26	1669	1695	1
Total non-OECD countries	1097	5494	6591	17
OECD countries	96	3872	3968	2
World	1193	9365	10558	11

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